The Self Creation challenge to the cosmological 'concordance model'
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Abstract

The theory of Self Creation Cosmology is described and found to be as concordant as the standard cosmological 'concordance model' with local experiments and cosmological observations. However it does not require the speculative hypotheses of inflation, dark matter or dark energy. The theory is highly predictive and when its only free parameter, H, is fixed empirically, all other cosmological constraints are then determined and found to be consistent with present observations. It is highly testable and challenges General Relativity in the geodetic precession measurement to be made by the Gravity Probe B satellite. The new theory predicts a N-S geodetic plus Thomas precession about a direction perpendicular to the plane of the orbit of 4.4096 arcsec/yr, that is, 2/3 of that of General Relativity. The predictions of the 'frame dragging' precession of that experiment are equal in both theories that is 0.0409 arcsec/yr. Furthermore, there are at least two other experiments that will distinguish between the two theories, which should be performed at the earliest opportunity, if the geodetic measurement proves to be consistent with the theory. These experiments ask the questions, "Do photons fall at the same rate as particles?" and "Is the Casimir force coupled to curvature?"

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1 Introduction

1.1 A Possible Challenge to the Standard Model

By the year 2003 the standard cosmological model was generally thought to be concordant with all observations, especially the very precise WMAP data set. The General Relativity (GR) 'Hot Big Bang' model, having been continually refined since the 1970's, today comprises the standard 'concordance model'. It is now thought to be firmly established by observational evidence beyond any reasonable doubt. This paper questions that certitude.

It is to be noted that the standard model does indeed fit the data, but only because of several additions made since the mid 1970's. At that time the GR model was found to contain the well-known density, smoothness and horizon problems. These were resolved by the addition of the hypothesis of inflation, which arose out of the Higgs field, a quantum mechanical approach to the origin of inertial mass.

This brought with it the additional problem that subsequent observations of galaxy clustering and gravitational lensing seemed to indicate that the value of the density parameter was only about one third whereas inflation required unity [1]; thus the initial inflation theory did not seem to fit the data.

Moreover, primordial cosmic abundances in the standard Big Bang scenario constrained the baryon density to only about 4 per cent of the critical density. Therefore it seemed that about one quarter of the universe's mass had not been accounted for. The additional supposition was thus made that this consisted of non-baryonic 'dark matter' of unknown identity.

Subsequent observations of Type IA Supernovae, [2], [3], as well as concordance with other observations, including the microwave background and galaxy power spectra, implied that the universe was accelerating.

Furthermore, an analysis of the anisotropies of the Cosmic Microwave Background (CMB) obtained from the WMAP data was seen to be consistent with a spatially flat universe. When interpreted within a GR environment this 'flatness' indicated that the total density of the universe was equal to, or very close to, the critical density, thereby apparently resolving the observed density disagreement with inflation.

Therefore it seemed that about another two thirds of the universe's mass had not been accounted for. Again an additional supposition was made, this time that this component consisted of 'dark energy', also of unknown

identity but having an 'anti-gravity' effect, in that it made cosmic expansion accelerate, thus apparently resolving the distant Type 1a supernovae data. There have been many unverified suggestions as to its nature such as: a dynamical cosmological 'constant', quintessence, decaying vacuum energy, or gravitational leakage from extra dimensions.

In the present epoch the required densities of both dark matter and dark energy are approximately equal and, to within an order of magnitude, they approximate the baryonic density. There appears to be no explanation for these perplexing coincidences, except perhaps an anthropic argument, but this was exactly the type of improbability that inflation was meant to correct. Nevertheless, such has been the effectiveness of these additions to the basic Big Bang theory that it is now generally considered that the detailed observational verification of the present model consisting of 23 per cent dark matter, 73 per cent dark energy and just 4 per cent ordinary matter has been robustly established.

However it may be prescient to ask, "Is not the inclusion into the standard cosmological concordant model of first inflation, then dark matter, and now dark energy, a modern example of adding 'extra epicycles', in a manner analogous to the ancient Ptolemaic system?"

The force of this question is, of course, dependent on the existence of a viable alternative theory that does not require the continual addition of extra hypotheses. It is the intention of this paper to argue that such an alternative does indeed exist; it is Self Creation Cosmology (SCC).

2   The Principles of SCC

The original SCC paper [4] was published in 1982. In that paper cosmologies were explored in which the matter field might be created out of self-contained gravitational and scalar fields. Two theories were postulated; the first was rejected on the grounds of non-concordant experimental violation of the Equivalence Principle, and the second was an early version of the present theory. That paper has generated some interest over the last twenty years and has been discussed in over forty-five citations. (see references [5] - [52])

The latest version of the theory, which will simply be referred to henceforth as SCC, can be introduced by remembering that Einstein gave some consideration to two concepts that are not fully included in GR, these are the local conservation of energy and Mach's Principle. At various times since

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the publication of Einstein's GR papers these concepts have been considered independently, in SCC they are considered together.

The first non-GR concept, which is the Local Conservation of Energy, can be appreciated by considering the conservation of four-momentum, P^ν, of a projectile in free fall, which is a fundamental property of any metric theory such as GR as it necessarily follows from the Equivalence Principle. As a consequence the energy or 'relativistic mass' of a particle, (P^0), is not conserved, except when measured in a co-moving frame of reference, or in the Special Relativity (SR) limit. In any metric theory a particle's rest mass is necessarily invariant as it is mathematically identical to the norm of the four-momentum vector. This requirement in the present SCC defines the Einstein frame (EF) of the theory. The local non-conservation of energy is a consequence of the fact that energy is not a manifestly covariant concept, that is, its value is relative to the inertial frame of reference in which it is measured. As the Equivalence Principle does not allow a preferred frame there is no definitive value for energy in any metric theory.

The second non-(fully)GR concept is Mach's Principle. This suggests that inertial frames of reference should be coupled to the distribution of mass and energy in the universe at large, hence one would actually expect there to be a preferred frame, that is, a frame in which the universe as a whole might be said to be at rest, in which P^0 is conserved, in apparent contradiction to the spirit of the Equivalence Principle. In fact such a frame of reference does appear to exist, it is that in which the Cosmic Background Radiation (CBR) is globally isotropic.

These two problems are linked and resolved together in the new SCC theory by the proposal that energy is to be locally conserved when measured in a particular, preferred, frame of reference as selected by Mach's principle, that is that of the Centre of Mass (CoM) of the system. This proposal defines what is called the Jordan (energy) Frame [JF(E)] of SCC, in which rest mass is required to include gravitational potential energy, as defined in that CoM frame of reference.

The requirement to locally conserve energy in such a Jordan Frame thus selects the CoM frame of reference as a "preferred foliation of space-time", to use Butterfield and Isham's expression [53]. Therefore, and although the question is not explored in this paper, in the future it might be pertinent to investigate whether such a preferred reference frame provides any insight into the problems at the gravitation and quantum theory interface.

SCC is an adaptation of the Brans Dicke (BD) theory in which the con-

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servation requirement has been relaxed to allow the scalar field to interact with matter. The scalar field that determines inertial mass, $\phi \approx \frac{1}{G_N}$, is coupled to the large scale distribution of matter in motion, described by the BD field equation, [54], which takes the simplest general covariant form:

$$\Box \phi = 4\pi\lambda T_M \ ,$$ (1)

T_M is the trace, $(T_M{}^\sigma{}_\sigma)$, of the energy momentum tensor describing all non-gravitational and non-scalar field energy. In this theory the Brans Dicke parameter λ is determined to be unity. [10]

The gravitational field equations are modified to explicitly include Mach's principle, following BD, [53], by including the energy-momentum tensor of a scalar field energy $T_{\phi\,\mu\nu}$

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi}{\phi}\left[T_{M\mu\nu} + T_{\phi\,\mu\nu}\right] \ .$$ (2)

where $T_{M\mu\nu}$ is the energy momentum tensors describing the matter field.

In SCC the conservation requirement is relaxed to allow mass to be created out of the gravitational and scalar fields according to the Principle of Mutual Interaction (PMI), in which the scalar field is a source for the matter-energy field if and only if the matter-energy field is a source for the scalar field.

$$\nabla_\mu T_M^{\cdot\,\mu}{}_\nu = f_\nu\left(\phi\right)\Box\phi = 4\pi f_\nu\left(\phi\right)T_M \ .$$ (3)

As a consequence photons still do traverse null-geodesics, at least *in vacuo,*

$$\nabla_\mu T_{em}{}^\mu{}_\nu = 4\pi f_\nu\left(\phi\right)T_{em} = 4\pi f_\nu\left(\phi\right)\left(3p_{em} - \rho_{em}\right) = 0$$ (4)

where p_{em} and ρ_{em} are the pressure and density of an electromagnetic radiation field with an energy momentum tensor $T_{em\,\mu\nu}$, in which $p_{em} = \frac{1}{3}\rho_{em}$ and where it has been shown, [7], [10], that

$$f_\nu\left(\phi\right) = \frac{1}{8\pi\phi}\nabla_\nu\phi \ .$$ (5)

SCC can be thought of as a semi-metric theory in which the BD theory is adapted to include the local conservation of energy. It is described as 'semi-metric' as although particles do not obey the Equivalence Principle, photons still do. This local conservation of energy requires the energy expended

in lifting an object against a gravitational field to be translated into an increase in rest mass. If $\Phi_N(x^\mu)$ is the dimensionless Newtonian gravitational potential defined by a measurement of acceleration in a local experiment in a frame of reference co-moving with the CoM,

$$\frac{d^2 r}{dt^2} = -\nabla \Phi_N(r) \tag{6}$$

and normalized so that $\Phi_N(\infty) = 0$, then the local conservation of energy requires (with $c = 1$)

$$\frac{1}{m_p(x^\mu)} \boldsymbol{\nabla} m_p(x^\mu) = \boldsymbol{\nabla} \Phi_N(x^\mu) \ , \tag{7}$$

where $m_p(x^\mu)$ is measured locally at x^μ. This has the solution

$$m_p(x^\mu) = m_0 \exp[\Phi_N(x^\mu)] \ , \tag{8}$$

$$\text{where} \qquad m_p(r) \to m_0 \qquad \text{as} \qquad r \to \infty \ .$$

2.1 The SCC Conformal Transformation

The Jordan Frame (JF) of SCC requires mass creation, ($\nabla_\mu T^\mu_{M\ \nu} \neq 0$), therefore the scalar field is non-minimally connected to matter. The JF Lagrangian density is,

$$L^{SCC}[g, \phi] = \frac{\sqrt{-g}}{16\pi} \left(\phi R - \frac{\omega}{\phi} g^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi \right) + L^{SCC}_{matter}[g, \phi] \ , \tag{9}$$

In a general conformal transformation $\widetilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$, mass is transformed according to

$$m(x^\mu) = \Omega \widetilde{m}_0 \tag{10}$$

where $m(x^\mu)$ is the mass of a fundamental particle in the JF and $\widetilde{m}_0$ its invariant mass in the EF. Therefore the local conservation of energy in the SCC JF, Equations 8 and 10, require

$$\Omega = \exp[\Phi_N(x^\mu)] \ . \tag{11}$$

Now, the conformal dual of the Lagrangian density, Equation 9, [55], [56], by such a general transformation is

$$L^{SCC}[\widetilde{g},\widetilde{\phi}] \;\; = \;\; \frac{\sqrt{-\widetilde{g}}}{16\pi}\left[\widetilde{\phi}\widetilde{R} + 6\widetilde{\phi}\widetilde{\Box}\ln\Omega\right] + \widetilde{L}^{SCC}_{matter}[\widetilde{g},\widetilde{\phi}] \tag{12}$$
$$-\frac{\sqrt{-\widetilde{g}}}{16\pi}\left[2\left(2\omega+3\right)\frac{\widetilde{g}^{\mu\nu}\widetilde{\nabla}_\mu\Omega\widetilde{\nabla}_\nu\Omega}{\Omega^2} + 4\omega\frac{\widetilde{g}^{\mu\nu}\widetilde{\nabla}_\mu\Omega\widetilde{\nabla}_\nu\widetilde{\phi}}{\Omega} + \omega\frac{\widetilde{g}^{\mu\nu}\widetilde{\nabla}_\mu\widetilde{\phi}\widetilde{\nabla}_\nu\widetilde{\phi}}{\widetilde{\phi}}\right] \;.$$

The transformation of $\widetilde{\phi}$ is treated in the earlier paper [7], where it is shown that Gm is invariant and, as in the EF $\widetilde{m}_0$ is defined to be invariant $\widetilde{G}$, and hence $\widetilde{\phi}$, are therefore constant. Thus in this frame $\widetilde{\nabla}_\nu\widetilde{\phi} = 0$. Hence if the following conditions are met: $\omega = -\frac{3}{2}$ and $\widetilde{\Box}\ln\Omega = 0$, Equation 12 reduces to the canonical GR Langrangian density:

$$L^{SCC}[\widetilde{g}] = \frac{\sqrt{-\widetilde{g}}}{16\pi G_N}\widetilde{R} + \widetilde{L}^{SCC}_{matter}[\widetilde{g}] \;, \tag{13}$$

where matter is now minimally connected. In fact the value $\omega = -\frac{3}{2}$ has not been arbitrarily chosen, but it is determined from the first principles of the theory [10]. Furthermore, the condition, $\widetilde{\Box}\ln\Omega = 0$, is the vacuum condition, $\widetilde{\Box}\widetilde{\Phi}_N\left(\widetilde{x}^\mu\right) = 0$, as this reduces to $\widetilde{\nabla}^2\widetilde{\Phi}_N\left(\widetilde{x}^\mu\right) = 0$ in a harmonic coordinate system. Therefore, in this theory the conformal transformation of the Jordan Frame, Equation 9, into the Einstein Frame, Equation 13, results in canonical GR *in vacuo*. As energy is locally conserved in this Jordan Frame it has been given the specific designation JF(E).

As a result of the SCC conformal equivalence with canonical GR *in vacuo*, SCC test particles follow the geodesics of GR in solar system experiments. Consequentially the SCC predictions for all the experiments tested to date are equal to those of GR.

These SCC principles have the consequence that in the Jordan Frame, in which energy is locally conserved in the Centre of Mass frame of reference, a photon has constant frequency and its energy is conserved even when passing through a gravitational field, [7]. Gravitational red shift is interpreted as a gain of potential energy, and hence mass, of the measuring apparatus, rather than the loss of (potential) energy by the photon.

3 The Standard Formulae of SCC

3.1 The SCC Field Equations

The SCC Action Principle gives rise to the following set of equations, [7]:
    The scalar field equation

$$\Box\phi = 4\pi T_M \ , \tag{14}$$

The gravitational field equation

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R \ = \ \frac{8\pi}{\phi}T_{M\mu\nu} - \frac{3}{2\phi^2}\left(\nabla_\mu\phi\nabla_\nu\phi - \frac{1}{2}g_{\mu\nu}g^{\alpha\beta}\nabla_\alpha\phi\nabla_\beta\phi\right) \tag{15}$$
$$+ \frac{1}{\phi}\left(\nabla_\mu\nabla_\nu\phi - g_{\mu\nu}\Box\phi\right) \ ,$$

Finally, the creation equation, which replaces the conservation equation

$$\nabla_\mu T_M{}^\mu{}_\nu = \frac{1}{8\pi}\frac{1}{\phi}\nabla_\nu\phi\Box\phi \ . \tag{16}$$

These field equations are manifestly covariant, there is no preferred frame of reference or absolute time. However in order to solve them one has to adopt a specific coordinate system; the CoM of the system in the spherically symmetric One Body Case, or that of the co-moving fluid of the cosmological solution. In those frames of reference there is a specific coordinate time as in the standard GR solutions. These JF(E) solutions of SCC, moreover, have the property not only of being in the local Machian frame of reference but also of locally conserving mass-energy.

3.2 The Spherically Symmetric Solution

The Robertson parameters are, [7],

$$\alpha_r = 1 \qquad \beta_r = 1 \qquad \gamma_r = \frac{1}{3} \ , \tag{17}$$

and therefore the standard form of the Schwarzschild metric is

$$d\tau^2 \ = \ \left(1 - \frac{3G_N M}{r} + ..\right)dt^2 - \left(1 + \frac{G_N M}{r} + ..\right)dr^2 \tag{18}$$
$$-r^2 d\theta^2 - r^2\sin^2\theta d\varphi^2 \ .$$

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The formula for ϕ is

$$\phi = G_N^{-1} \exp(-\Phi_N) \tag{19}$$

and that for m is, (Equation 8),

$$m_p\left(x_\mu\right) = m_0 \exp(\Phi_N).$$

3.3 Local Consequences of the Theory

The violation of the Equivalence Principle manifests itself as an extra force that acts on particles, but not photons, which acts in a similar way to gravitational force, but of one third the strength in the opposite direction, and which is conflated with it. Therefore there are two Gravitational constants, G_N, which applies to particles and measurable in Cavendish type experiments as the standard Newtonian constant and G_m, which applies to photons and is that constant that determines the curvature of space-time. These two constants relate together, [7], according to:

$$G_N = \frac{2}{3}G_m \;. \tag{20}$$

Hence, if normal Newtonian gravitational acceleration is g, the acceleration of a massive body caused by the curvature of space-time is $\frac{3}{2}g$ 'downward' compensated by an 'upward' acceleration caused by the scalar field of $\frac{1}{2}g$.

Finally in the JF(E) the radial inward acceleration of a freely falling body is given by the non-Newtonian expression

$$\frac{d^2r}{dt^2} = -\left\{1 - \frac{G_N M}{r} + ...\right\} \frac{G_N M}{r^2} \;. \tag{21}$$

In the earlier paper it was seen that the effect of this non-Newtonian perturbation was to compensate for the effect of the scalar field upon the curvature of space-time.

The acceleration experienced by a freely falling particle is given by

$$m_0 \frac{d^2r}{dt^2} = -m(r)\frac{G_N M}{r^2} \;. \tag{22}$$

We see that m_0 can be thought of as 'inertial-mass', which measures inertia and $m(r)$ as 'gravitational mass', which interacts with the gravitational field with

$$\underset{r\to\infty}{Lim}\; m(r) = m_0 \;.$$

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As described in the original paper, [7], the conformal equivalence between the JF(E) of SCC and canonical GR, results in the predictions of SCC in the standard tests being identical with GR. It was seen in detail in that paper that in the JF(E) of the theory, the action of the non-conservation of the energy-momentum tensor for matter results in an extra 'scalar-field' force, mentioned above, which acts on particles and which exactly compensates for the scalar field perturbation of the curvature of the space-time manifold. Nevertheless two definitive experiments were suggested in that paper, which examine the interaction of the photon and the vacuum energy fields with ordinary matter. Since then the geodetic precession measurement has been also recognised as another definitive experiment.

4 The Cosmological Case

4.1 Deriving the General Cosmological Equations

Using the Cosmological Principle the usual assumptions of homogeneity and isotropy can be made to obtain the cosmological solutions to the field equations.

The privileged CoM frame in which physical units may be defined for any epoch is now the "rest frame" for the universe as a whole. Presumably it should be identified physically with that frame in which the microwave background radiation is globally isotropic.

There are two questions to ask in order that a Weyl metric may be set up spanning extended space-time, "What is the invariant standard by which objects are to be measured?" and "How is that standard to be transmitted from event to event in order that the comparison can be made?" In the SCC EF, and GR, the principle of energy-momentum conservation, i.e. invariant rest mass, determines that standard of measurement to be fixed rulers and regular clocks. In the SCC JF(E), on the other hand, the principle of the local conservation of energy determines that standard of measurement to be a "standard photon", which is to be taken from the CMB in the cosmological case. The inverse of its frequency determines the standard of time and space measurement, and its energy determines the standard of mass, all defined in the CoM, Machian, frame of reference. According to SCC, a gravitational field, i.e. the curvature of space-time, is to be described in the JF(E), whereas observations using atomic apparatus, based on an atomic clock, are referred

to the EF. The two frames have to be transformed as appropriate.

There are four equations to consider that are treated in the earlier paper, [7]. The first is the Gravitational Field Equation 15, which is exactly the same as the BD equation with $\omega = -\frac{3}{2}$. The second is the Scalar Field Equation 1. In GR the third equation is the conservation equation, which is replaced in SCC by the Creation Field Equation 16. The fourth equation is some equation of state, such as the dust filled universe $p = 0$, or the early radiation dominated universe in which $p = \frac{1}{3}\rho$. The SCC field equations demand an exotic equation of state.

The two gravitational cosmological equations are

$$\left(\frac{\dot{R}}{R}\right)^2 + \frac{k}{R^2} = +\frac{8\pi\rho}{3\phi} - \frac{\dot{\phi}\dot{R}}{\phi R} - \frac{1}{4}\left(\frac{\dot{\phi}}{\phi}\right)^2 , \tag{23}$$

$$\frac{\ddot{R}}{R} + \left(\frac{\dot{R}}{R}\right)^2 + \frac{k}{R^2} = -\frac{1}{6}\left(\frac{\ddot{\phi}}{\phi} + 3\frac{\dot{\phi}\dot{R}}{\phi R}\right) + \frac{1}{4}\left(\frac{\dot{\phi}}{\phi}\right)^2 . \tag{24}$$

The scalar cosmological equation

$$\ddot{\phi} + 3\frac{\dot{\phi}\dot{R}}{R} = 4\pi\left(\rho - 3p\right) . \tag{25}$$

The creation cosmological equation is

$$\dot{\rho} = -3\frac{\dot{R}}{R}\left(\rho + p\right) + \frac{1}{8\pi}\frac{\dot{\phi}}{\phi}\left(\ddot{\phi} + 3\frac{\dot{\phi}\dot{R}}{R}\right) . \tag{26}$$

(It is a moot point whether the scalar field ϕ is generated by the distribution of mass and energy via Equation 25, or whether mass is generated by the scalar field via Equation 26.)

Finally the equation of state remains

$$p = \sigma\rho , \tag{27}$$

where the equations determine $\sigma = -\frac{1}{3}$ in the SCC universe.

4.2 The SCC Cosmological Solution

The five independent Equations, 23, 24, 25, 26 and 27 and the sixth relationship, provided by the conservation of a free photon's energy in the JF(E) together with Stephan's Law, provide a solution for the six unknowns $R(t)$, $\phi(t)$, $\rho(t)$, $p(t)$, k and σ. There are also the boundary conditions at $t = t_0$ (present epoch), R_0, ϕ_0, ρ_0, and p_0.

The cosmological 'self-creation equation' is found to be, [7],

$$\rho = \rho_0 \left(\frac{R}{R_0} \right)^{-3(1+\sigma)} \left(\frac{\phi}{\phi_0} \right)^{\frac{1}{2}(1-3\sigma)} , \tag{28}$$

which is the equivalent GR expression with the addition of the last factor representing cosmological 'self-creation'. However for a photon gas $\sigma = +\frac{1}{3}$ so Equation 28 reduces to its GR equivalent, consistent with the Principle of Mutual Interaction that there is no interaction between a photon and the scalar field,

$$\rho_{em} = \rho_{em\,0} \left(\frac{R}{R_0} \right)^{-4} . \tag{29}$$

Since $\rho_{em} \propto T_{em}^4$ where T_{em} is the Black Body temperature of the radiation, the GR relationship $T_{em} \propto R^{-1}$ still holds. Also as the wavelength λ_{em} of maximum intensity of the Black Body radiation is given by $\lambda_{em} \propto T_{em}^{-1}$, the SCC JF(E) retains the GR relationship

$$\lambda_{em} \propto R . \tag{30}$$

However in the SCC JF(E) λ_{em} is constant for a free photon, even over curved space-time, and it is particle masses that vary. Therefore in the JF(E) Equation 30 becomes simply

$$R = R_0 . \tag{31}$$

In the Jordan energy frame the universe is static when measured by light, that is, as a co-expanding "light ruler" is unable to detect the expanding universe there is no expansion.

The cosmological gravitational and scalar field equations are solved to yield

$$\phi = \phi_0 \exp\left(H_0 t \right) , \tag{32}$$

where H_0 is Hubble's 'constant' in the present epoch, defined by $t = 0$, and $\phi_0 = G_N^{-1}$. By definition G_N is the value measured in "Cavendish type"

experiments in the present epoch. Note the theory admits a cosmological ground state solution, $g_{\mu\nu} \to \eta_{\mu\nu}$ and $\nabla_\mu \phi = 0$ only when $t \to -\infty$, that is at the "Big Bang" itself. Equations 25, 27, 31, 32 and $\sigma = -\frac{1}{3}$ yield

$$\frac{8\pi\rho}{\phi_0} = H_0^2 \exp\left(H_0 t\right) \ . \tag{33}$$

This can be written in the form

$$\rho = \rho_0 \exp\left(H_0 t\right) \tag{34}$$

$$\text{where } \rho_0 = \frac{H_0^2}{8\pi G_N} \ , \tag{35}$$

if now, as usual, the critical density is defined $\rho_c = \frac{3H_0^2}{8\pi G_N}$, then $\rho_0 = \frac{1}{3}\rho_c$. Hence the cosmological density parameter Ω_c

$$\Omega_c = \frac{1}{3} \ . \tag{36}$$

Therefore, in this theory there is no need for 'Dark Energy'. The cosmological density parameter Ω_c comprises of baryonic (plus any cold dark matter) and radiation (plus any hot dark matter) components together with that of false vacuum energy. As the total pressure is determined by the constraints of the cosmological equations $\sigma = -\frac{1}{3}$, together with Equation 34, the total cosmological pressure is given by

$$p = -\frac{1}{3}\rho_0 \exp\left(H_0 t\right) \ . \tag{37}$$

To explain this it is suggested that a component of the cosmological pressure and density is made up of false vacuum. In other words there is a "remnant" vacuum energy made up of contributions of zero-point energy from every mode of every quantum field that would have a natural energy "cut-off" $E_{\max}$, which in the cosmological case is determined, and limited, by the solution to the cosmological equations. If the total density comprises of both a baryon density together with a false vacuum density then the cosmological equations require

$$\rho_b = 2\rho_f \ . \tag{38}$$

Therefore the density parameter for cold matter (visible and dark) is

$$\Omega_b = \frac{2}{9} \approx 0.22 \ . \tag{39}$$

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Assuming baryon conservation in a static universe, the inertial mass of a fundamental particle must be given by

$$m_i = m_0 \exp\left(H_0 t\right) \ .\tag{40}$$

4.3   The Transformation Into the Einstein Frame (EF)

Measurements of curvature or the wavelength/energy of a photon are made in the JF(E), however the physics of atomic structures is naturally described in the EF. It is now necessary to transform the units used in the JF(E) into the system used in physical measurement using atomic apparatus; that is the EF. The two frames are conformally related, where Ω is the parameter of conformal transformation,

$$g_{\mu\nu} \rightarrow \widetilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu} \ ,$$

where the interval is invariant under the transformation

$$d\tau^2 = -g_{\mu\nu}dx^\mu dx^\nu = -\widetilde{g}_{\mu\nu}d\widetilde{x}^\mu d\widetilde{x}^\nu \ .\tag{41}$$

Now mass transforms according to Equation 10

$$m\left(x^\mu\right) = \Omega\widetilde{m} \ ,$$

therefore Equation 40 requires in the cosmological solution to the field equations

$$\Omega = \exp\left(H_0 t\right) \ .\tag{42}$$

From which the transform of length and time is obtained by integrating along space-like and time-like paths respectively,

$$\widetilde{L} = L_0 \exp\left(H_0 t\right)\tag{43}$$

$$\text{and } \triangle\widetilde{t} = \triangle t \exp\left(H_0 t\right) \ .\tag{44}$$

These transformations are consistent with using the Bohr/Schrödinger/Dirac models of an atom to measure length and time under mass transformation.

The two time scales relate to each other as follows

$$\widetilde{t} = \frac{1}{H_0}\exp\left(H_0 t\right) \qquad \text{and} \qquad t = \frac{1}{H_0}\ln\left(H_0\widetilde{t}\right) \ ,\tag{45}$$

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where $\widetilde{t}$ is time measured from the "Big Bang" in the EF, and t is time measured from the present day in the JF(E).

Applying this transformation to the universe's scale factor in two steps, the first step yields

$$\widetilde{R} = R_0 \exp\left(H_0 t\right) \ . \tag{46}$$

This expression uses mixed frames, that is, length is in the EF and time is in the JF(E). If we now substitute for t in Equation 46 we obtain the scale factor of the universe in the EF.

$$\widetilde{R} = R_0 \frac{\widetilde{t}}{\widetilde{t_0}} \ . \tag{47}$$

Thus when measured by physical, that is atomic, rulers and clocks the universe is seen to expand linearly from a "Big Bang". The deceleration parameter

$$q = -\left(\frac{\ddot{\widetilde{R}}}{H^2 \widetilde{R}}\right) = 0 \ . \tag{48}$$

Therefore the horizon, smoothness and density problems of classical GR cosmology, which all arise from a positive, non zero q, do not feature in SCC. Hence it is unnecessary to invoke Inflation in this theory and indeed, with Equation 46, SCC might be considered to be a form of "Continuous Inflation".

The curvature constant k is given by Equations 24 and 23

$$\frac{k}{R_0^2} = +\frac{1}{12}H_0^2 \ , \tag{49}$$

so k is positive definite,

$$k = +1 \ , \tag{50}$$

that is, the universe is finite and unbounded. From Equation 49 R_0 can be derived in terms of the Hubble time

$$R_0 = \sqrt{12}H_0^{-1} \ . \tag{51}$$

5 Summary

In the JF(E), where energy is conserved but energy-momentum is not, photons are the means of measuring length, time and mass. Proper mass increases with gravitational potential energy and as a consequence cosmological red shift is caused by a secular, exponential, increase of particle masses and not cosmological expansion. The universe is static, in which atomic rulers 'shrink' exponentially, and eternal, in which atomic clocks 'speed up' exponentially.

In the EF, where energy-momentum is conserved and particle proper masses are invariant, atoms are the means of measuring length, time and mass. As the scalar field adapts the cosmological equations the universe expands linearly from a Big Bang, it is a "freely coasting" universe.

5.1 Observational consequences of the Theory

In order to compare the theory with observations and experiments to date it is important to note both that, *in vacuo* SCC test particles follow GR geodesic trajectories and, although the Robertson parameters are given by Equation 17 as: $\alpha_r = 1$, $\beta_r = 1$ and $\gamma_r = \frac{1}{3}$, so that in particular we have $\gamma_r = \frac{1}{3}$, which is less than the GR equivalent, this is compensated in most observations by an increase in the gravitational 'constant': $G_m = \frac{3}{2}G_N$. Hence the theory of SCC is concordant with all experiments and observations to date that otherwise have been thought to verify GR. For example, in the Gravity Probe B satellite experiment the 'frame dragging' prediction is given by the expression:

$$\overset{3}{g}_{i0} = -4G_m \left(\frac{1+\gamma_r}{2} \right) \int \frac{\overset{1}{T}^{i0}(x',t)}{|x-x'|} d^3x \ . \tag{52}$$

so the SCC values for $G_m = \frac{3}{2}G_N$ and $\gamma_r = \frac{1}{3}$ give the same result as GR in which $G_m = G_N$ and $\gamma_r = 1$. On the other hand in the geodetic prediction the precession is given by the expression

$$\frac{1}{2}(2\gamma_r + 1)\frac{G_m M_{\oplus}}{R^3}\mathbf{v}_s \times \mathbf{X} \ , \tag{53}$$

which in GR, where $\gamma_r = 1$ and $G_m = G_N$, predicts a precession for the Gravity B Probe gyroscope of 6.6144 arc sec/yr about a direction perpendicular to the plane of the orbit. However, in SCC $\gamma_r = \frac{1}{3}$ and $G_m = \frac{3}{2}G_N$, so

the theory predicts a value 5/6 of this or just 5.5120 arc sec/yr. In SCC there is also a Thomas precession, which has to be subtracted from the geodetic precession, of

$$\frac{1}{6} \frac{G_m M_\oplus}{R^3} \mathbf{v}_s \times \mathbf{X} \; , \qquad (54)$$

Therefore, the SCC theory prediction of a N-S precession of the GP-B gyroscope is $\frac{2}{3}$ of that of the GR prediction, or just 4.4096 arcsec/yr.This crucial measurement will be the first experiment ever that will be able to distinguish between the two theories.

The consequence of this theory is the realisation that there are two distinct ways of interpreting observations of the universe. In a laboratory on Earth scientific observations defining units of length, time and mass/energy have to be referred to an atomic standard. However, astrophysical and cosmological observations only sample photons and not particles from the depths of the universe. How then does the measurement of standard units made in a laboratory here and now on Earth relate to an event that occurred millennia ago in a distant part of the universe? In particular the problem is rooted in the variation of energy levels, and hence frequency and wavelength, of photons over and above that caused by the Doppler effect, because of gravitational and cosmological red shift.

Based on the Equivalence Principle, GR defines the proper rest mass of a particle to be invariant, therefore that theory requires the measure of standard units to be atomic 'rigid' rulers and atomic 'regular' clocks. However, in doing so it violates the conservation of mass-energy as described in the Introduction section above.

On the other hand, if a gravitational theory were to include the local conservation of energy, as in the theory of SCC, then an atom's rest mass would vary with gravitational potential energy, whereas a photon's energy would be decoupled from the effects of curvature. If this indeed occurs then a choice may be made as to the invariant standard by which units of length, time and mass/energy are measured. This choice of the unit used for comparison is between a 'standard' atom, taken from a laboratory, or a 'standard' photon, sampled from the CMB. Observations of the cosmos would then fall into one of two complementary interpretations: either that of the Jordan Frame static universe, which is eternal with no origin in time, or that of the Einstein Frame strictly linearly expanding universe, which has had an 'origin' in a 'Big Bang' at one 'Hubble Time' in the past. Either model would be a valid interpretation of the data, the JF(E) would be the appropriate

frame to observe gravitational orbits and the curvature of space-time, and the EF would be the appropriate frame to observe atomic processes such as primordial nucleosynthesis.

It is remarkable that both these models, the static universe and the freely coasting universe, have already been independently investigated and both have been found to be surprisingly concordant with accepted cosmological constraints, including Big Bang nucleosynthesis abundances, distant Type Ia supernovae observations and the WMAP CMB anisotropy data.

The static universe has been investigated heuristically by Ostermann [57], and found to be able to fit the standard concordance model perfectly [58].

The strictly linearly expanding or freely coasting model has been investigated by Kolb, [59], Batra, Lohiya, Mahajan and Mukherjee, [60], Dev, Safonova, Jain and Lohiya, [61], Gehaut, Mukherjee, Mahajan and Lohiya, [62], and Gehaut, Kumar, Geetanjali and Lohiya,[63]. Their motivation in exploring such a cosmology was the recognition that the model would not have suffered from the original density, smoothness and horizon problems of the standard GR theory. The latter paper reviews their results and finds the freely coasting universe fits the Type 1a supernovae data. Moreover, the recombination history gives the location of the primary acoustic peaks of the WMAP data in the same range of angles as that given in standard cosmology. Safonova, [64], in her PhD thesis, reports that gravitational lensing is also consistent with the linearly expanding freely coasting model. A further remarkable result of this model is the analysis of nucleosynthesis in the Big Bang. They, [60], calculate that a baryon entropy ratio of $\eta = 5 \times 10^{-9}$ yields 23.9 per cent Helium and 10^8 times the metallicity of the standard scenario, which although large is still of the same order of magnitude as seen in the lowest metallicity objects. Therefore, one prediction of the theory is that a significant proportion of intergalactic medium metallicity should be primordial.

A further consequence is, interestingly, that the production of this amount of helium requires a baryon density parameter of about 0.2. As the total non-false vacuum energy density is required by SCC to be only 0.22, there is no need for unknown dark matter. In SCC, this component of the cosmic density parameter is in the form of intergalactic cold baryonic matter.

Furthermore the cosmological solution requires the universe to have an overall density parameter of only one third, yet be closed and conformally spatially flat. Hence the theory does not require dark energy, nor a significant amount of dark matter, to account for the present cosmological constraints.

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Finally as described in a former e-print, [8], a 'time-slip' exists in SCC between atomic 'clock' time on one hand and gravitational ephemeris and cosmological time on the other, which would result in an apparent sunwards acceleration of the Pioneer spacecraft as indeed is observed, [67], [68], [69] and [57].

There are three experiments that are able to distinguish between the two theories, one of which is the Gravity Probe B geodetic measurement described above. The other two are described in references [7] and [9]. These ask the questions, "Do photons fall at the same rate as particles?" and "Is there a cut-off to the Casimir force that approaches zero as curvature approaches flatness detectable in the solar system somewhere beyond the orbit of Jupiter?"

The first of these experiments might consist of an annulus of tiny mirrors designed to reflect one half of a split beam along a path length of about two kilometres while the other half is simply reflected once along a short path length before the two half beams are recombined in an interferometer. Inverting the apparatus in Earth orbit would produce a shift, or not, in the interference pattern depending on whether the photon beam is falling at a different, or the same rate as the apparatus. This experiment might be a suitable addition to the STEP (Satellite Test of the Equivalence Principle) programme, [70], either as an extra component of the planned spacecraft, or as a separate experiment possibly carried in the Space Shuttle.

The second experiment would measure the Casimir force between two close plates at an increasing range from the Sun and other large planets in order to detect a cut-off that depended on the Sun's gravitational field. It would be a suitable addition to the "yo-yo" craft concept, suggested by Michael Martin Nieto and Slava G. Turyshev, [71], in order to test the Pioneer anomaly.

It is suggested that these experiments be performed at the earliest opportunity if the geodetic measurement should indeed prove to be consistent with the Self Creation theory.

6   Conclusion

In conclusion SCC does not require inflation to resolve the density, smoothness and horizon problems, as they do not exist in the theory; it does not require dark matter as the mass density of baryonic matter is determined to be 0.22, and it does not require dark energy as the model is conformally flat

with a total density of 0.33. It does require a false vacuum energy density, which is required by the cosmological equations to be 0.11, thus resolving the 'lambda' problem. It is therefore a testable theory, which is as concordant with the cosmological constraints as the standard GR model, but without these additional hypotheses, and it should be considered as a valid alternative to that theory.

7   References

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